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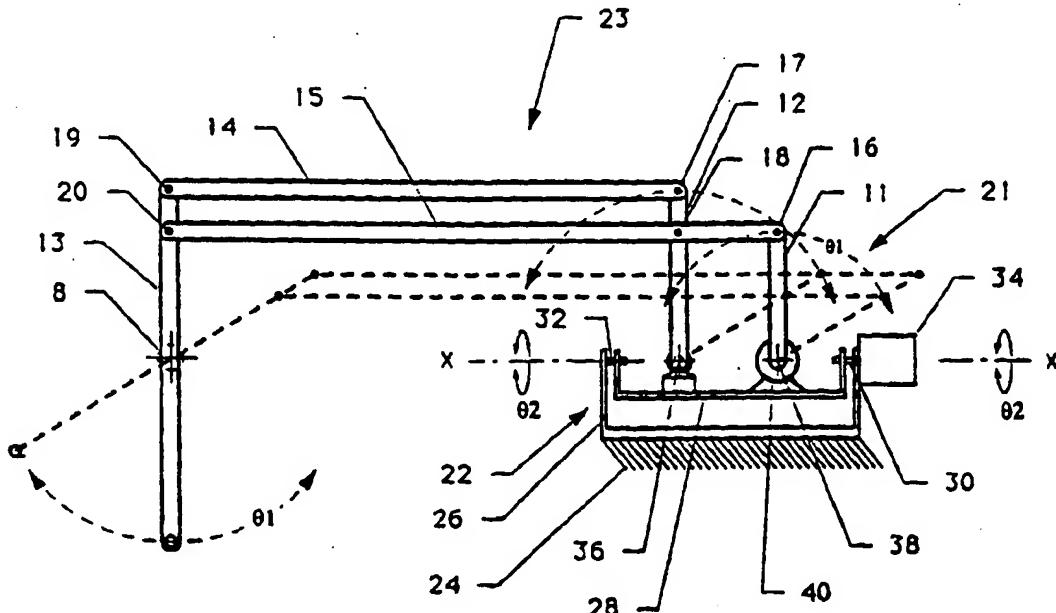
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(54) Title: REMOTE CENTER POSITIONER



**(57) Abstract**

The invention is directed to a remote center positioner (23) used to support an instrument and provide a center of spherical rotation, remote from any bearings or mechanical supports, at a desired location of the instrument. The remote center positioner (23) is particularly useful in laparoscopic surgery to constrain a surgical instrument to move around a fixed center of rotation remote from any bearings or mechanical supports and coincident with an entry incision in the abdominal wall.

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## REMOTE CENTER POSITIONER

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## BACKGROUND OF THE INVENTION

The present invention is directed to a remote center positioner used to support an instrument and provide a center of spherical rotation, remote from any bearings or mechanical supports, at a desired location of the instrument.

Specifically, the remote center positioner is useful in laparoscopic surgery to constrain a surgical instrument to move around a fixed center of rotation remote from any bearings or mechanical supports and coincident with an entry incision in the patient's abdominal wall.

In standard laparoscopic abdominal surgery, the patient's abdomen is insufflated with gas, and cannulas are passed through small (approximately 1/2 inch) incisions to provide entry ports for laparoscopic surgical instruments.

The laparoscopic surgical instruments generally include an laparoscope for viewing the surgical field, and working tools such as clamps, graspers, scissors, staplers, and needle holders. The working tools are similar to those used in conventional (open) surgery, except that the working end of each tool is separated from its handle by an approximately 12-inch long extension tube. To perform surgical procedures the surgeon passes instruments through the cannulas and manipulates them inside the abdomen by sliding them in and out through the cannulas, rotating them in the cannulas, and "levering" (pivoting) them around centers of rotation approximately defined by the incisions in the muscles of the abdominal wall. The abdominal incisions do not provide stable reference positions or points of rotation, and so in order to maintain accurate positional control of an instrument during manipulation, the surgeon may need to manually constrain it to pivot around a fixed point coincident with the incision. Manual support of the pivot point is particularly important when the surgeon manipulates laparoscopes or other heavy

instruments. Mechanical clamping devices are used to support the instruments in fixed orientations, but these devices do not provide a remote center of rotation for positioning the instruments.

5 In robotically assisted and telerobotic laparoscopic abdominal surgery the position of the surgical instruments is controlled by servo motors rather than directly by hand or with fixed clamps. With servo control, a means must be provided to ensure that the surgical instrument is constrained 10 to move around a fixed center of rotation coincident with an entry incision in the patient's abdominal wall. Any other types of motion such as translation or rotation about other centers could cause patient injury.

15 Heretofore, there have been mechanisms directed to providing assistance in surgery. Thus, U.S. Patent 4,756,655 to Jameson is directed to a manipulating mechanism having a control handle adapted to be positioned freely in three dimensions, a fixture for supporting a tool to be positioned, a linkage system which causes the end of the tool to move in 20 the same direction as the control handle and a support structure. The linkage system includes a first linkage connected between the control handle and an effective ball-and-socket joint and a second linkage connected between the effective ball and socket joint and the fixture. Each linkage 25 includes four link members rotatably connected in a parallelogram and a gimbal connected to one of the link members for mounting the linkage from the support structure.

30 The linkage system includes a first linkage connected between the control handle and a joint and a second linkage connected between the first linkage and the fixture. In the preferred embodiments, the linkage system is comprised of two motion translation mechanisms connected in series through an effective ball-and-socket joint, where each 35 translation mechanism is essentially a pantograph adapted for rotation with respect to the support structure about two perpendicular axes. The motion of the control handle induces oppositely (or similarly, depending on the embodiment) directed motion of the ball-and-socket joint by means of one

translation mechanism which in turn causes similarly directed motion of the tool by means of the second translation mechanism so that the motion of the tool is in the same direction as the motion of the control handle. The linkage 5 system is directed to a master reflection system controlling a slave reflection mechanism and does not provide a remote center of spherical rotation.

U.S. Patent 4,143,652 to Meier and Dbaly discloses a surgical retaining device for holding a surgical instrument in 10 place, typically with hooks. The device includes a holder block for displaceably securing the surgical retaining device at a stationary object and at least one insert element into which there can be inserted and fixedly clamped the surgical instrument. Between the insert element and the holder block 15 there is arranged a double-arm pivotable stand possessing an intermediate pin joint. The pivotable stand is connected at one end by means of a ball-and-socket joint at the insert element and at its other end by means of a further ball-and-socket joint with an overhang arm which can be fixedly clamped 20 at random elevational and angular positions with respect to the holder block at the latter.

A paper given at the IEEE Engineering in Medicine and Biology Society 11th Annual International Conference in 1989 entitled SMOS: Stereotaxical Microtelemanipulator for 25 Ocular Surgery shows a structure for use in ocular vitrectomy, and other medical fields such as radial keratotomy and plastic surgery. Figures 2 and 3 of the paper shows the mechanical structure of the SMOS. A carrier holds a rotatably mounted curved wrist. An instrument holder is movably mounted to the 30 wrist for carrying an instrument or needle for working in the eye keeping the needle centered on the entrance aperture. This is described as realized in spherical coordinates in a reference whose zero point is the entrance aperture A. The mechanism creating these movements, which are in themselves 35 the main actions of the vitrectomy operation, is called the wrist of the microtelemanipulator.

An article entitled "Robotic Surgery" in the March 1993 issue of IEEE Engineering in Medicine and Biology shows a

motorized frame (Fig. 8) for use in prostate surgery. Figure 8 shows a schematic layout of the main mechanical components of the device called SARP. The working envelope is small and can be flexibly constrained using mechanical stops to improve 5 safety. The envelope is approximately the frustum of a cone. Several cones may be needed, depending on the size of the prostate, to remove the unwanted enlarged tissue from within the prostate.

The manual frame can only produce conical cavities 10 because it is manually driven. However, the motorized frame is capable of producing both conical and barrel shape cavities. As a start, conical cavities are advocated to avoid moving along more than one axis at a time. Conical cavities are easy to produce using hot loop electrosurgery. Similar to 15 the manual frame, a ring shape frame fitted with a diametrical arch is a carriage that carries the resectoscope. A C-shaped bracket fixed to the resectoscope helps ease the introduction of the motorized frame to the resectoscope. The axes are designed to be driven by motors. Back driving is possible 20 when the servo action is disabled. Successive cuts are made by extending and retracting the cutting loop repeatedly and turning on the cutting current at the return stroke of the cutter. The ring moves to a new position for each cut. Several conical cavities can be resected from the prostate to 25 relieve blockage. To achieve one or more of these conical cavities inside the prostate, the frame is fixed to a head travel so that it can move axially along the rotation axis of the ring axis.

None of the above-mentioned devices provide a light 30 weight simple apparatus for providing a remote center of rotation for use in surgery with minimal obstruction of the surgical field as is disclosed and claimed herein.

#### SUMMARY OF THE INVENTION

In a broad aspect an apparatus is provided for 35 moving an instrument about a spherical center of rotation at a desired location of the instrument. A base support means is adapted to be fixedly mounted to a surface. First linkage

means are pivotally mounted on the base support means for rotation about an axis. Holding means are provided for holding an instrument in a position so that the desired remote center of spherical rotation of the instrument lies on the 5 axis of rotation of the first linkage means. A second linkage means is connected to the holding means and pivotally connected to the first linkage means so that the remote center of spherical rotation of the instrument is maintained at the desired location.

10 The present invention provides a device for providing a remote center of spherical rotation for an instrument. A pivot joint having an x-x axis of rotation has a first linkage having one end pivotally mounted thereon. The axis of rotation of the first linkage is normal to and intersects the x-x axis. The other end is remote from the pivot joint. A parallelogram linkage is provided with a driving end and a remote end. The parallelogram linkage includes two sets of two corresponding members pivotally connected in a parallelogram. The parallelogram linkage is 15 located in a plane parallel with the first linkage and has the driving end pivotally connected to the remote end of the first linkage. A mounting means for an instrument extends from the remote end of the parallelogram linkage. The mounting means is adapted to position the axis of the instrument held thereby 20 to intersect the x-x axis to provide a center of spherical rotation for the instrument at a desired location.

25 In a more specific aspect the invention provides a device for providing a remote center of spherical rotation for an instrument for conducting laparoscopic surgery including a base support means adapted to be fixedly mounted to a surface and a pivot plate pivotally mounted to the base support means and having a rotational axis thereabout. At least a pair of linkage elements are extended from the pivot plate in parallel plane relationship. One end of the linkage elements is 30 pivotally mounted in spaced apart relationship to the pivot plate. A parallelogram linkage means is connected to the linkage elements and includes two sets of two corresponding link members pivotally connected in a parallelogram, one of 35

the sets of the two corresponding link members adapted to remain always parallel to the rotational axis, one of the link members of the set of corresponding link members adopted to remain always parallel to the rotational axis being pivotally connected to both linkage elements, one of the linkage elements being pivotally connected to both link members adopted to remain always parallel to the rotational axis. The parallelogram linkage means has an operating end and a driving end. An instrument element extends from the operating end of the parallelogram linkage means for movement therewith. The instrument element intersects the rotational axis at the location on the element desired for the remote center of rotation.

The remote center positioner is useful in a variety of applications. For example, supporting a microscope or other instrument to scan over and inspect a spherical surface. Various tools or instruments (manually or robotically positioned) that are passed through narrow entry ports can be supported by the apparatus of the present invention. Other uses include robotically-assisted positioning of an laparoscope for laparoscopic surgery, with the user commanding the position and orientation of the laparoscope via digital speech recognition, foot-switches, head-tracking or eye-tracking devices; support of manually-positioned laparoscopes or other surgical instruments during laparoscopic surgery; and telerobotic manipulation of laparoscopic surgical instruments (laparoscopes and various working tools) in which the positions of the working end of the tools are under servo control, and follow the motions of a surgeon's hands as he manipulates input control devices at a location that may be remote from the patient. Position, force, and tactile feedback sensors may be employed to transmit position, force, and tactile sensations from the working tool tips back to the surgeon's hands as he operates the telerobotic system.

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#### OBJECTS OF THE INVENTION

A particular object of the present invention is to provide apparatus useful to support an instrument or the like

and includes the ability to move the instrument to perform a variety of tasks while maintaining a center of spherical rotation at a desired location of the instrument. Additional objects and advantages of the present invention will become 5 apparent from the description of the various embodiments thereof read in light of the attached drawings which are made part of this specification.

#### BRIEF DESCRIPTION OF THE DRAWINGS

10 Fig. 1 is a elevation view of an embodiment of a remote center positioner;

Fig. 2 is a elevation view of the preferred embodiment of a remote center positioner;

15 Fig. 2a is an enlarged sectional view taken at section a-a of Figure 2;

Fig. 3 is an end view of the preferred embodiment of the remote center position of Fig. 2;

20 Fig. 4 is a elevation view illustrating an embodiment of the remote center positioner in accordance with the invention having an adjustable center distance;

Fig. 5 is an elevation view illustrating a motor driven application of the remote center positioner in accordance with the present invention;

25 Fig. 6 is an elevation view illustrating a manual application of the remote center positioner in accordance with the present invention;

Fig. 7 is an elevation view of another embodiment of apparatus of the invention;

30 Fig. 7a is a sectional view taken at line a-a of Fig 7;

Fig. 8 is an elevation view of another embodiment of apparatus of the invention; and

Fig. 8a is a sectional view taken at line a-a of Fig. 8.

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#### DESCRIPTION OF THE INVENTION

Fig. 1 is an elevation view of an embodiment of a remote center positioner in a basic form in accordance with

the present invention. A first linkage means is indicated generally by the numeral 21 and a second linkage in the form of a parallelogram is indicated by the numeral 23. The first linkage means is pivotally mounted on a base plate for 5 rotation about an x-x axis. The second linkage means is pivotally connected to the first linkage means and is adapted to move in a plane parallel to the first linkage. Five link members (including extensions thereof), 11, 12, 13, 14, and 15 are connected together with pivot joints 16-20. A portion of 10 element 13 extends beyond pivot 20 of the parallelogram linkage. The parallelogram linkage has an operating end at link member 13 and a driving end at link member 12. The elongated element 13 may, as desired later, carry a surgical instrument or other device. The pivot joints allow relative 15 motion of the link members only in the plane containing them.

A parallelogram linkage is formed by corresponding link members 14, 15 and link members 12 and 13. The portions of link members 14 and 15 of the parallelogram are of equal length as are the portions of members 12 and 13 of the 20 parallelogram. These members are connected together in a parallelogram for relative movement only in the plane formed by the members. A rotatable joint generally indicated by the numeral 22 is connected to a suitable base 24. The rotatable joint 22 is mounted on a base plate 26 adapted to be fixedly 25 mounted to the base support means 24. A pivot plate 28 is pivotally mounted to base plate 26 by suitable means at, such as, pivots 30, 32. Thus pivot plate 28 may be rotated about axis x-x through a desired angle  $\theta_2$ . This may be accomplished manually or by a suitable pivot drive motor 34.

30 A first linkage is pivotally mounted on the pivot plate 28 of the rotatable joint 22. The linkage elements 11, 12 and the link members are relatively stiff or inflexible so that they may adequately support an instrument used in surgical operations. Rods made of aluminum or other metal are 35 useful as such links. The linkage elements 11 and 12 are pivotally mounted on base plate 28 for rotation with respect to the rotatable joint by pivots 36 and 38. At least one of the pivots 36, 38 is positioned so that its axis of rotation

is normal to and intersects the x-x axis. Movement may occur manually or may occur using a linkage drive motor 40. The first linkage is also shaped in the form of a parallelogram formed by linkage elements 11, and 12; the portion of link member 15 connected thereto by pivots 16, 18; and base plate 28. One of the link members 15 is thus utilized in both the first 21 and second 23 linkage means. Linkage element 12 also forms a common link of both the first linkage means 21 and the second linkage means 23. In accordance with the invention, a remote center of spherical rotation 8 is provided by the above described embodiment of apparatus when the linkage element 11 is rotated and/or when pivot plate 28 is rotated about axis x-x. Thus the end of element 13 can be moved through desired angles  $\theta_1$  and  $\theta_2$  or rotated about its own axis while the remote center of rotation remains at the same location.

The preferred embodiment of apparatus assembled in accordance with the present invention is illustrated in Figures 2, 2a and 3. Figure 2 is an elevation view, Figure 2a is an enlarged sectional view taken at a-a of Figure 2 and figure 3 is an end view of the remote positioning apparatus. Many of the elements of the preferred embodiment are the equivalent to elements of the Figure 1 embodiment. These elements will be designated with the same numbers primed in Figures 2 and 3. Thus a pivot plate 28' is rotatably mounted on a base support means 26' by suitable means such as pivots 30', 32'. The pivot plate and the base plate form a rotatable joint 22' which has a rotation axis designated as x-x. The base plate may be fixedly mounted to a suitable base support means 24'.

Two linkage elements 11' and 12' extend from the pivot plate 28'. Mounting means 36' and 38' are provided to pivotally mount one end of each of the linkage elements to the pivot plate. The axis of rotation of the linkage elements are normal to and intersecting the x-x axis. A channel shaped link member 115 is pivotally connected by suitable pivot joints 16' and 18' to the other ends of linkage elements 11', 12' (respectively) equidistant from pivot plate 28'. A corresponding link member 15' is located internally of link

member 115 and is pivotally connected to the upper end of linkage element 12'. A link member 13' corresponding in length to the link member 12' between pivots 17', 18' is pivotally connected to link member 15' at pivot 19' and to link member 115 at pivot 20'. An instrument mounting means 44 is fixedly mounted to link member 13' for movement therewith. The axis of an instrument held in the instrument mounting means 44 intersects the x-x axis of the rotating joint 22'. Thus an instrument held in the mounting means would have a remote center of spherical rotation about the position indicated by the numeral 8' in Fig. 2.

A drive motor 434 incorporating a shaft-angle position sensor is operably connected to the pivot plate 28'. A second drive motor 440 incorporating a shaft-angle position sensor is operably connected to linkage element 11'. Suitable motor drive and control circuits may be connected to motor/sensor 440 and motor/sensor 434 via power and sensor cables 436 and 435 (respectively) to operate the present apparatus under open-loop or closed-loop servo control. The details of the mounting arrangement for the instrument mounting means are shown in Fig. 2a which is a sectional view taken at a-a of Fig. 2. As there shown the mounting means 44 is fixedly connected via multiple-axis force and torque sensor 400 and pin member 118 to link member 13' for movement therewith. Link member 13' is pivotally connected at pivot 20' to the channel shaped link member 115 by bearing means 116, 117 formed about pin member 118. Link member 15' is pivotally connected to link member 13' at 19' by means of bearing means 120 and pin member 121.

A suitable sensor interface circuit may be connected to the force and torque sensor 400 via cable 401 so that sensor signals arising from forces and torques applied to an instrument supported in the mounting means 44 can be detected and used for monitoring or controlling operation of the present apparatus. For example, the sensor signals can be used as feedback signals in master-slave force-reflecting telerobotic servo control of the invention such that the input control device responds only to forces exerted on the

supported instrument and is not affected by inertial loads, gravity forces, or external forces acting on linkage elements other than mounting means 44.

5 An apparatus is provided for moving an instrument about a spherical center of rotation at a desired location of the instrument. A base support means is adapted to be fixedly mounted to a surface. First linkage means 11', 12' are pivotally mounted on the base plate for rotation about an axis. A holding means 44 is provided for holding an 10 instrument in a position so that the desired remote center of spherical rotation of the instrument intersects the axis and a second linkage means 15', 115 and 13' is connected to the holding means and pivotally connected to the first linkage means by pivots 17', 18', 16' whereby the remote center of 15 spherical rotation of the instrument is maintained at the desired location.

Fig. 4 is a schematic elevation view of another embodiment of apparatus assembled in accordance with the present invention. In many instances it may be desirable to 20 have a means of adjusting the remote center of rotation 8' relative to the mounted position of base plate 26'. Thus it would be desirable to axially extend or retract the horizontal members 14', 15' of the parallelogram linkage. The length of the two corresponding members 14', 15' must be increased or 25 decreased in equal amounts to maintain the parallelogram geometry of the linkage.

The axial length adjustment could be provided in many ways. For example, as shown in Fig. 4, a portion of members 14', 15' are provided with racks 42, 44. Tubular members 46, 48 enclose members 14', 15'. The members 14', 15' are extended or retracted by suitable means such as drive 30 motor 50, motor lead 51 and drive belt 52. Other means for axially extending or retracting the members are available. For example, coupled lead screws could be used or the members 35 could be manually fixed into the desired position in the tubular members using ratchets, pins or spring detents.

Figure 5 illustrates an embodiment of apparatus assembled in accordance with the invention wherein a motor

driven arrangement is positioned on the operating end of the parallelogram linkage. A drive unit 60 is connected by power and control cable 62 to a source of power and control and a cannula 64 is provided which may be passed through a patient's 5 abdominal wall. An instrument 66 is attached to an operating element 68 and may be manipulated as indicated in Figure 5. The remote center positioners as described heretofore will maintain the center of spherical rotation at position 80 while the instrument 66 is being manipulated.

10 Figure 6 is an elevation view illustrating a manual application of the remote center positioner of the present invention. A handle 71 for operating a surgical instrument 73 is connected to the operating end of the remote center positioner. Movement of the cannula 75 will be constrained to 15 rotation about the center 80' of spherical rotation.

Figure 7 is an elevation view and Fig. 7a is a 20 sectional view taken at a-a of Fig. 7 of an embodiment of the invention which utilizes a flexible drive element in the linkage of the remote center positioner. A rotatable joint is indicated by the numeral 122. The rotatable joint rotates about an x-x axis. Thus pivot plate 128 can be rotated about pivots 130, 132 through a desired angle  $\theta_2$  with respect to 25 base plate 126. A linkage element 111 is pivotally mounted on the pivot plate by pivot 133. The pivot 133 is positioned so that its axis of rotation is normal to and intersects the x-x axis. A pulley 101 is positioned to be coaxial with the axis 30 of rotation of the pivot 133. It is evident that the term pulley can include wheels, sprockets or the like. The pulley is fixedly connected to the base plate 128 by suitable means such as screws 105, 107. Thus the pulley will not rotate with respect to the base plate 128.

35 A link member 114 is pivotally connected by pivot joint 116 to linkage element 111. A second pulley 121 coaxial with pivot 116 is fixedly connected to link member 114 by screws 146 and 147. A flexible drive link 135 such as a belt, chain, or a cable is connected around the pulleys 121, 101 in a non slip mode (such as a bicycle chain or timing belt). Pulleys 121 and 101 are of equal diameter as are pulleys 142

and 137. A link member 140 is pivotally connected to the operating end of link member 114 by means of pivot joint 141.

5 A third pulley 137 coaxial with pivot 141 is fixedly connected to link member 140 by means of screws 143, 145. A fourth pulley 142 coaxial with pivot 116 is fixedly connected to link element 111 by screws 160 and 161. A second flexible drive link 150 is connected around pulleys 137 and 142 in non slip relationship. Thus when linkage element 111 is rotated about pivot 133 by linkage drive motor 149 for example, the 10 motion is transmitted by the pulleys to link member 140 which is constrained to move in parallel relationship with element 111. In this manner a remote center of rotation is maintained as indicated by 180 in Fig. 7.

15 Figure 8 is an elevation view and Fig. 8a is a sectional view taken at a-a of Figure 8 of another embodiment of the present invention.

20 A rotatable joint is shown and is indicated generally by the number 222. The rotatable joint rotates about a x-x axis. Thus pivot plate 228 can be rotated around pivots 230, 232 through a desired angle  $\theta_2$ . A linkage element 211 is pivotally mounted on the pivot plate 228 by pivot 233. The axis of the pivot 233 is located normal to and intersecting the x-x axis of rotation. A pulley 201 is positioned to be coaxial with the axis of rotation of the 25 pivot 233. The pulley is fixedly connected to the base plate by suitable means such as screws 205, 207.

30 A pair of link members 214, 215 are pivotally connected to linkage element 211 by pivots 212 and 216 respectively. The other end of the link members 214 and 215 are pivotally connected to an instrument holding means or the like indicated by 240 by suitable pivot joints 241, 242. A second pulley 231 is fixedly connected to link element 215 by suitable screws 251, 252. The pulley 231 is mounted coaxially with the axis of rotation of the pivot joint 216. A flexible 35 drive link 260 is connected around both pulleys 201 and 231 in non slip relationship. The effect of this construction constrains link members 215 and 214 to remain parallel with the x-x axis during movement and also constrains element 240

to remain parallel with linkage element 211 during movement, thus causing the center of spherical rotation of the instrument or the like to remain at point 280.

5 The principles, preferred embodiments and modes of operation of the present invention have been described in the foregoing specification. However, the invention which is intended to be protected is not to be construed as limited to the particular embodiments disclosed. The embodiments are to be construed as illustrative rather than restrictive.

10 Variations and changes may be made by others without departing from the spirit of the present invention. Accordingly, all such variations and changes which fall within the spirit and scope of the present invention as defined in the following claims are expressly intended to be embraced thereby.

WHAT IS CLAIMED IS:

1. Apparatus for moving an instrument about a spherical center of rotation at a desired location of said instrument comprising:

5 a base support means adapted to be fixedly mounted to a surface;

10 a first linkage means, including at least a first rod, pivotally mounted on said base support means for rotation about an axis;

15 an instrument;

holding means holding said instrument in a position so that the desired remote center of spherical rotation of said instrument intersects said axis; and

20 15 a second linkage means, including at least a second rod, connected to said holding means for moving said holding means in a plane parallel to said second linkage means, said second linkage means being pivotally connected to said first linkage means so that said second rod remains parallel to said axis and said first rod remains parallel to said instrument, whereby said spherical center of rotation is maintained at the desired location of said instrument.

25 2. The apparatus of claim 1 further characterized in that both the first linkage means and the second linkage means include a parallelogram formed by pivotally connected rods wherein one of the rods is common to both parallelograms.

30 3. The apparatus of claim 1 further characterized in that the linkage means includes a drive assembly comprising at least a pair of pulleys of the same diameter, one of the pulleys being fixedly mounted to said second rod, the other of said pulleys being fixedly connected to said first linkage at a location other than said first rod and spaced apart from said second rod and a flexible element connected around the pulleys in non slip relationship.

4. The apparatus of claim 1 further characterized in that said first linkage means includes a first pulley fixedly mounted thereon;

5 said second linkage means includes a second pulley fixedly mounted thereon and spaced apart from said first pulley, said pulleys being of the same diameter; and

10 a flexible element connected around said pulleys in non slip relationship wherein a movement of one of said linkage means is transmitted to the other of said linkage means by said flexible element.

5. A device for providing a remote center of spherical rotation for an instrument comprising:

15 a rotatable joint having an x-x axis of rotation; a first linkage including two members;

20 pivot means pivotally mounting one end of said members on said rotatable joint, the axis of rotation of said pivot means being normal to and intersecting said x-x axis and the other end of said members remote from said rotatable joint;

25 a parallelogram linkage having a driving end and a remote end, said parallelogram linkage including two sets of two corresponding members pivotally connected in a parallelogram, said parallelogram linkage being in a plane parallel with said first linkage and having the driving end pivotally connected to the remote end of said first linkage means; and

30 a mounting means for an instrument extending from the remote end of the parallelogram linkage, said mounting means adapted to position the axis of an instrument held thereby to intersect the x-x axis of said rotatable joint at the location on the instrument desired as the center of spherical rotation.

35 6. A device for providing a remote center of spherical rotation for an elongated element comprising:

a base support means adapted to be fixedly mounted to a surface;

a pivot plate pivotally mounted to said base support means, and having a rotational axis x-x;

at least two linkage elements extending from said pivot plate;

5 means pivotally mounting one end of said linkage elements to said pivot plate, at least one of said means pivotally mounting said elements being on the x-x axis of said pivot plate, the axis of rotation of said linkage elements being normal to and intersecting said x-x axis;

10 a parallelogram linkage means including two sets of two corresponding link members pivotally connected in a parallelogram, said parallelogram linkage means having an operating end and a driving end;

15 an elongated element extending from the operating end of said parallelogram linkage means for movement therewith, said elongated element intersecting said x-x axis at the desired location of the remote center of spherical rotation on the elongated element; and

20 means pivotally connecting said driving end of said parallelogram linkage means with said linkage elements so that said parallelogram linkage means and said linkage elements are in parallel plane relationship and so that one set of said link members remains always parallel to said x-x axis, for all motions of said linkage means.

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7. A device for providing a remote center of spherical rotation for a tool element comprising:

a base support means adapted to be fixedly mounted to a surface;

30 a pivot plate pivotally mounted to said base support means, and having a rotational axis thereabout;

at least a pair of linkage elements extending from said pivot plate in parallel plane relationship;

35 means pivotally mounting one end of said elements in spaced apart relationship to said pivot plate, said means pivotally mounting at least one of said elements being on the rotational axis of said pivot plate, said means pivotally mounting said elements on the rotational axis of said pivot

plate having an axis of rotation normal to and intersecting said rotational axis;

5 a parallelogram linkage means including two sets of two corresponding link members pivotally connected in a parallelogram, one of the sets of the two corresponding link members adapted to remain always parallel to said rotational axis, said parallelogram linkage means having an operating end and a driving end;

10 a tool element extending from the operating end of said parallelogram linkage means for movement therewith, said tool element intersecting said rotational axis at the location on said tool element desired for the remote center of rotation; and

15 means pivotally connecting said driving end of said parallelogram linkage means with the linkage elements so that said parallelogram linkage means and said linkage elements are in parallel plane relationship and are movable in said planes.

20 8. The device of claim 7 further characterized in that two link members are substantially longer than the other two link members.

25 9. The device of claim 8 further characterized in that the longer link members are substantially horizontal.

10. The device of claim 7 further characterized in that one of the link members is a channel shaped element and encloses its corresponding link member.

30 11. The device of claim 8 further characterized in that one of the longer link members is a channel shaped element and encloses its corresponding link member.

35 12. The device of claim 11 further characterized in that the longer two link members are substantially horizontal.

13. The device of claim 7 further characterized in that the upper end of one of said linkage elements forms the

link member at the driving end of said parallelogram linkage means.

5 14. The device of claim 7 further characterized by a linkage drive motor operatively connected to one of said linkage elements for rotating said element.

10 15. The device of claim 14 further characterized in that a pivot drive motor is operatively connected to said pivotally mounted pivot plate for rotating said pivot plate.

15 16. The device of claim 7 further characterized in that at least one set of two corresponding link members is axially extendable and retractable an equal amount to maintain said parallelogram shape.

20 17. The device of claim 16 further characterized in that said at least one set of two corresponding link members is horizontal.

18. The apparatus of claim 7, further characterized in that a hand operated surgical instrument is operably connected to said elongated element for movement therewith.

25 19. The apparatus of claim 7 further characterized in that a motor driven surgical instrument is operably connected to said elongated element for movement therewith.

30 20. A device for providing a remote center of spherical rotation for a tool element comprising:

a base support means adapted to be fixedly mounted to a surface;

means, and having a rotational axis thereabout;

35 at least a pair of linkage elements extending from said pivot plate in parallel plane relationship;

means pivotally mounting one end of said elements in spaced apart relationship to said pivot plate, said means

pivottally mounting said elements being on the rotational axis of said pivot plate, the axis of rotation of said elements being normal to and intersecting said rotational axis;

5 a parallelogram linkage means including two sets of two corresponding link members pivottally connected in a parallelogram, one of the sets of the two corresponding link members adapted to remain always parallel to said rotational axis, one of the link members of said set of corresponding link members adopted to remain always parallel to said 10 rotational axis being pivottally connected to both linkage elements, one of said linkage elements being pivottally connected to both link members adopted to move parallel to said rotational axis, said parallelogram linkage means having an operating end and a driving end; and

15 an instrument element extending from the operating end of said parallelogram linkage means for movement therewith, said instrument element intersecting said rotational axis at the location on said instrument element desired for the remote center of rotation.

20

21. A device for providing a remote center of spherical rotation for a surgical instrument comprising a first linkage means formed in the shape of parallelogram having linkage members pivottally connected for relative motion 25 only in the plane containing them;

means for rotating said first linkage means about an x-x axis, said x-x axis being in parallel relationship to said plane;

30 a parallelogram linkage means having an operating end and a driving end, the driving end being pivottally connected to said first linkage means, one of the members of said first linkage means being also a member of said parallelogram linkage means thereby constraining said parallelogram linkage means to remain always parallel to said 35 plane;

and holding means on the operating end of said parallelogram linkage for holding an instrument so that the

desired center of spherical rotation of said instrument intersects said x-x axis.

22. A device for providing a remote center of  
5 spherical rotation for a surgical instrument comprising:  
a base support means adapted to be fixedly mounted  
to a surface;  
a pivot plate pivotally mounted to said base support  
means, and having a rotational axis x-x;  
10 at least two linkage elements extending from said  
pivot plate;  
means pivotally mounting one end of said linkage  
elements to said pivot plate, the axis of rotation of said  
linkage elements being normal to and intersecting to said x-x  
15 axis;  
a first link member pivotally connected to both of  
said link elements at points equal distance from said means  
pivotally mounting said link elements, a second link member  
pivotally connected to at least one of said linkage elements,  
20 a third link member pivotally connected to said first and  
second link members to connect said first and second link  
members and one of the link elements in a parallelogram shape  
and instrument holding means fixedly connected to said third  
link member element for movement therewith and adopted to hold  
25 said instrument in a position intersecting said x-x axis at a  
desired center of spherical rotation of said instrument;

23. The device of claim 22 further characterized in  
that said first and second link members are substantially  
30 longer than said third link member.

24. The device of claim 23 further characterized in  
that the longer link members are substantially horizontal.

35 25. The device of claim 23 further characterized in  
that one of the said first or second link members is a channel  
shaped element and encloses its corresponding link member.

26. The device of claim 22 further characterized in that said first link member is a channel shaped element and encloses its corresponding link member.

5 27. The device of claim 26 further characterized in that said first and second link members are substantially horizontal.

10 28. The device of claim 22 further characterized in that the upper end of one of said linkage elements forms one link member of said parallelogram linkage means.

15 29. The device of claim 22 further characterized by a linkage drive motor operatively connected to one of said linkage elements for rotating said element.

20 30. The device of claim 29 further characterized in that a pivot drive motor is operatively connected to said pivotally mounted pivot plate for rotating said pivot plate.

25 31. The device of claim 22 further characterized in that said first and said second link members are axially extendable and retractable in equal amount to maintain said parallelogram shape.

32. The device of claim 31 further characterized in that said first and second link members are horizontal.

30 33. The apparatus of claim 22 further characterized in that a hand operated surgical instrument is operably connected to said instrument holding means for movement therewith.

35 34. The apparatus of claim 22 further characterized in that a motor driven surgical instrument is operably connected to said instrument holding means for movement therewith.

35. Apparatus for moving an instrument about a spherical center of rotation at a desired location of said instrument comprising:

5 a base support means adapted to be fixedly mounted to a surface;

10 a first linkage means pivotally mounted on said base support means for rotation about an axis, said first linkage means including a pulley fixedly mounted thereon adjacent to said base plate;

15 an instrument;

20 holding means holding said instrument in a position so that the desired remote center of spherical rotation of said instrument intersects said axis;

25 a second linkage means connected to said holding means and pivotally connected to said first linkage means, said second linkage means including a pulley fixedly mounted thereon adjacent said pivotal connection to said first linkage means; and

30 a flexible chain element connected around said pulleys in non slip relationship whereby the remote center of spherical rotation of said instrument is maintained at the desired location as said linkage means are moved.

36. The device of claim 35 further characterized by 25 a linkage drive motor operatively connected to one of said linkage means for rotating said instrument.

37. The device of claim 35 further characterized in that a pivot drive motor is operatively connected to said 30 first linkage means for rotating said first linkage means.

38. The apparatus of claim 35 further characterized in that a hand operated surgical instrument is operably connected to said holding means for movement therewith.

35

39. The apparatus of claim 35 further characterized in that a motor driven surgical instrument is operably connected to said holding means for movement therewith.

40. A device for providing a remote center of spherical rotation for an instrument comprising:

5        a rotatable joint having an x-x axis of rotation;

      a first linkage including one member having one end pivotally mounted on said rotatable joint, the axis of rotation of the member of said first linkage being normal to and intersecting said x-x axis and the other end remote from said rotatable joint and a first pulley fixedly mounted on said rotatable joint in coaxial relationship with the axis of 10 rotation of said member;

      a parallelogram linkage having a driving end and a remote end, said parallelogram linkage including two sets of two corresponding members pivotally connected in a parallelogram, said parallelogram linkage being in a plane parallel with said first linkage and having the driving end pivotally connected to the remote end of said first linkage means, a second pulley fixedly mounted to one of the two corresponding members at the driving end of said parallelogram linkage coaxial with the pivotal connection between the 15 driving end and the remote end of said first linkage, said first and said second pulleys being of the same diameter;

      a flexible element connected in a non slip mode over said first and second pulleys; and

20        a mounting means for an instrument extending from the remote end of the parallelogram linkage, said mounting means adapted to position the axis of an instrument held thereby to intersect the x-x axis of said rotatable joint at the location on said instrument desired for the remote center 25 of spherical rotation.

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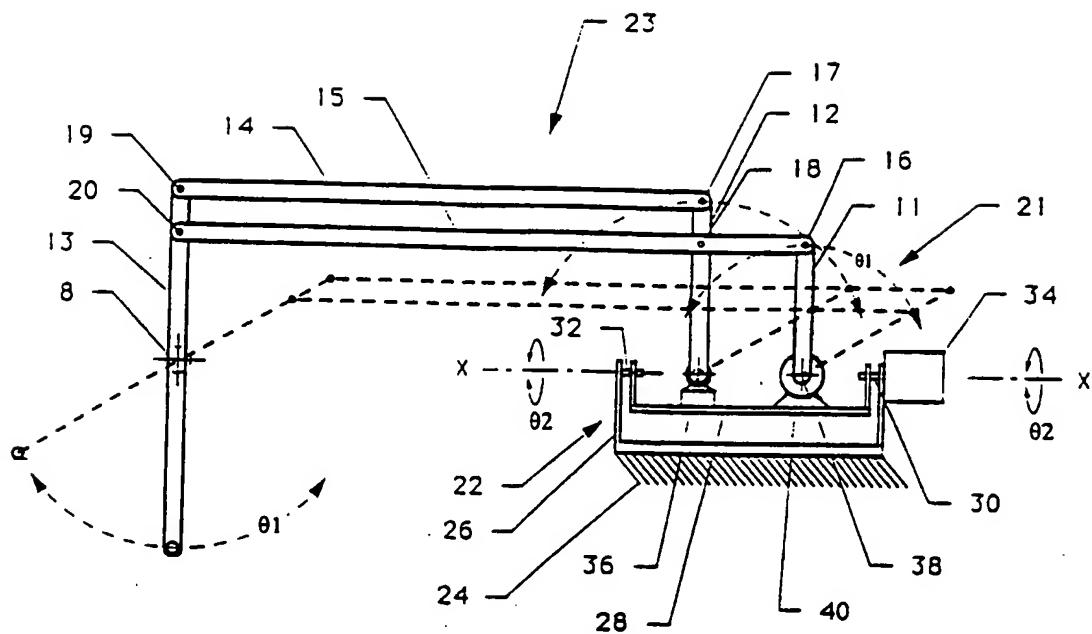
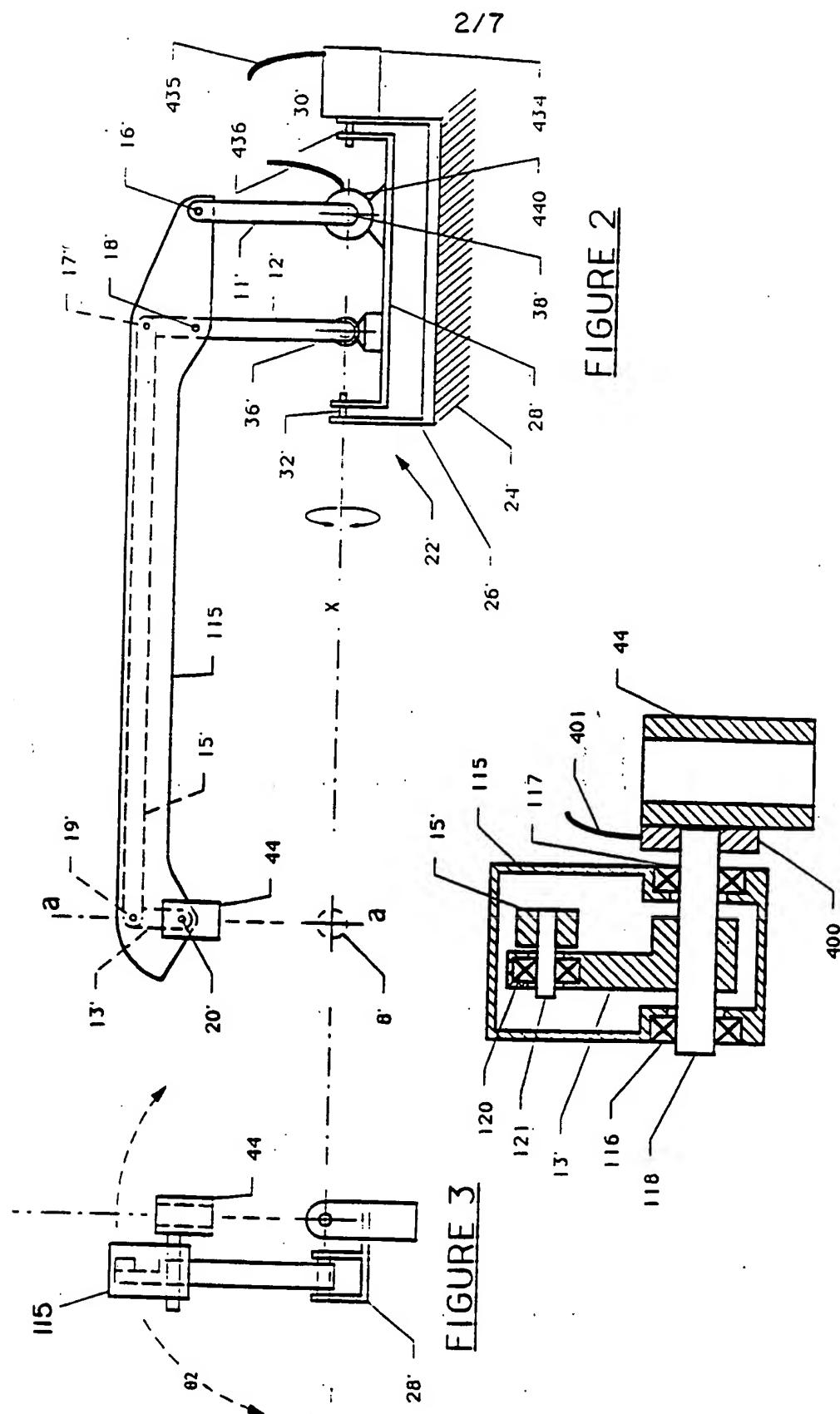


FIG. 1.

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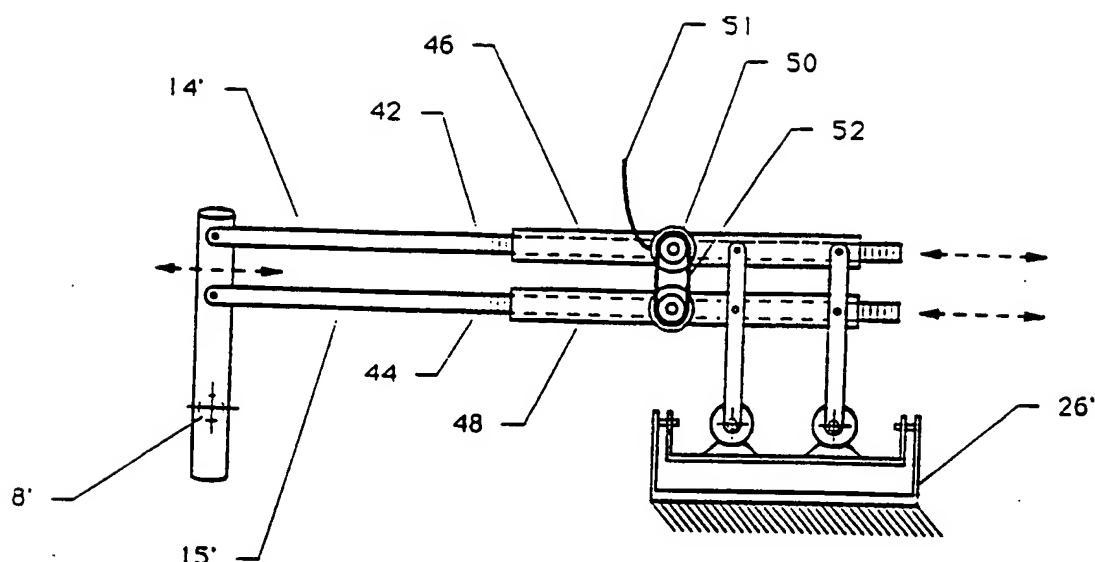


FIG. 4.

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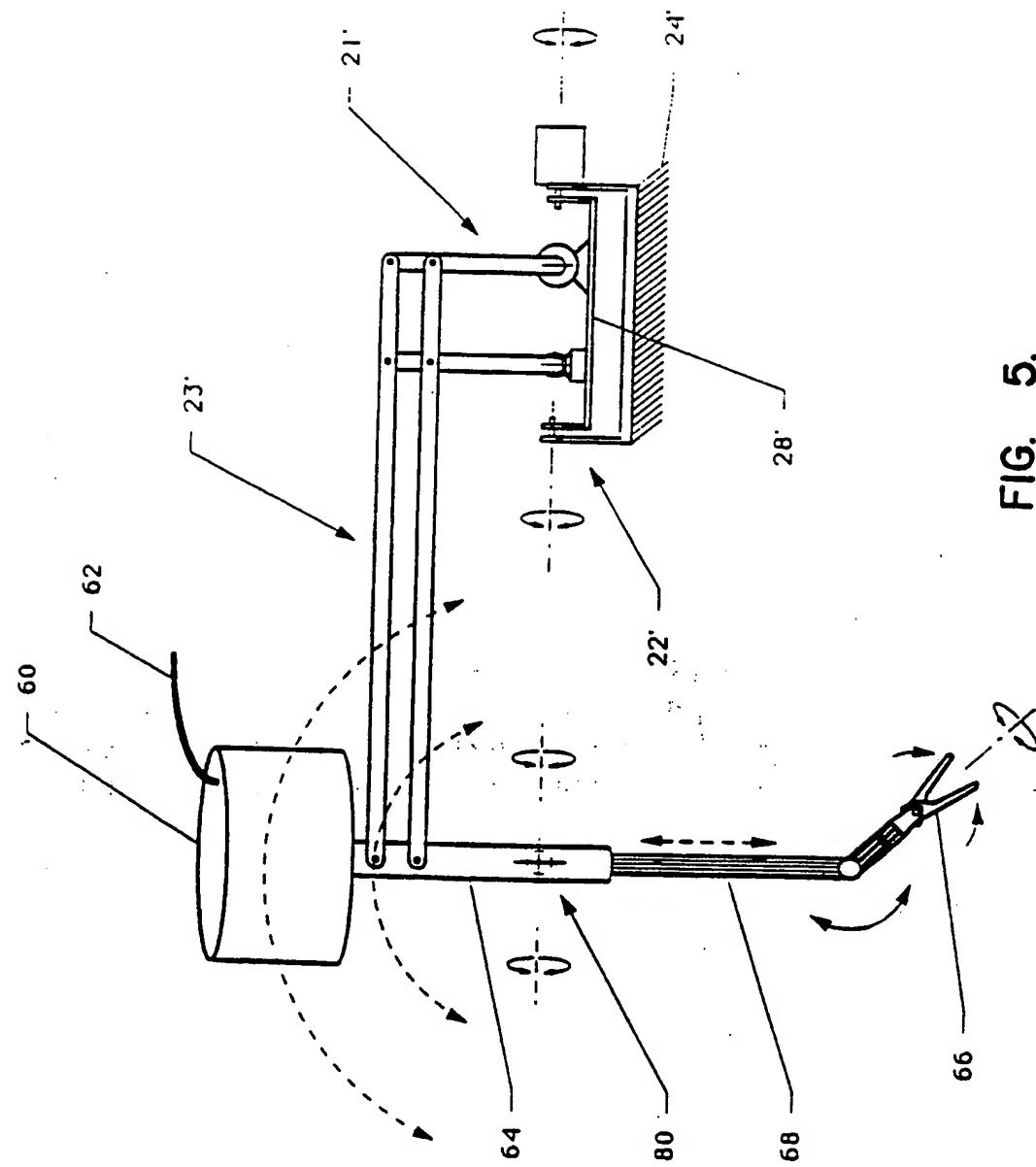


FIG. 5.

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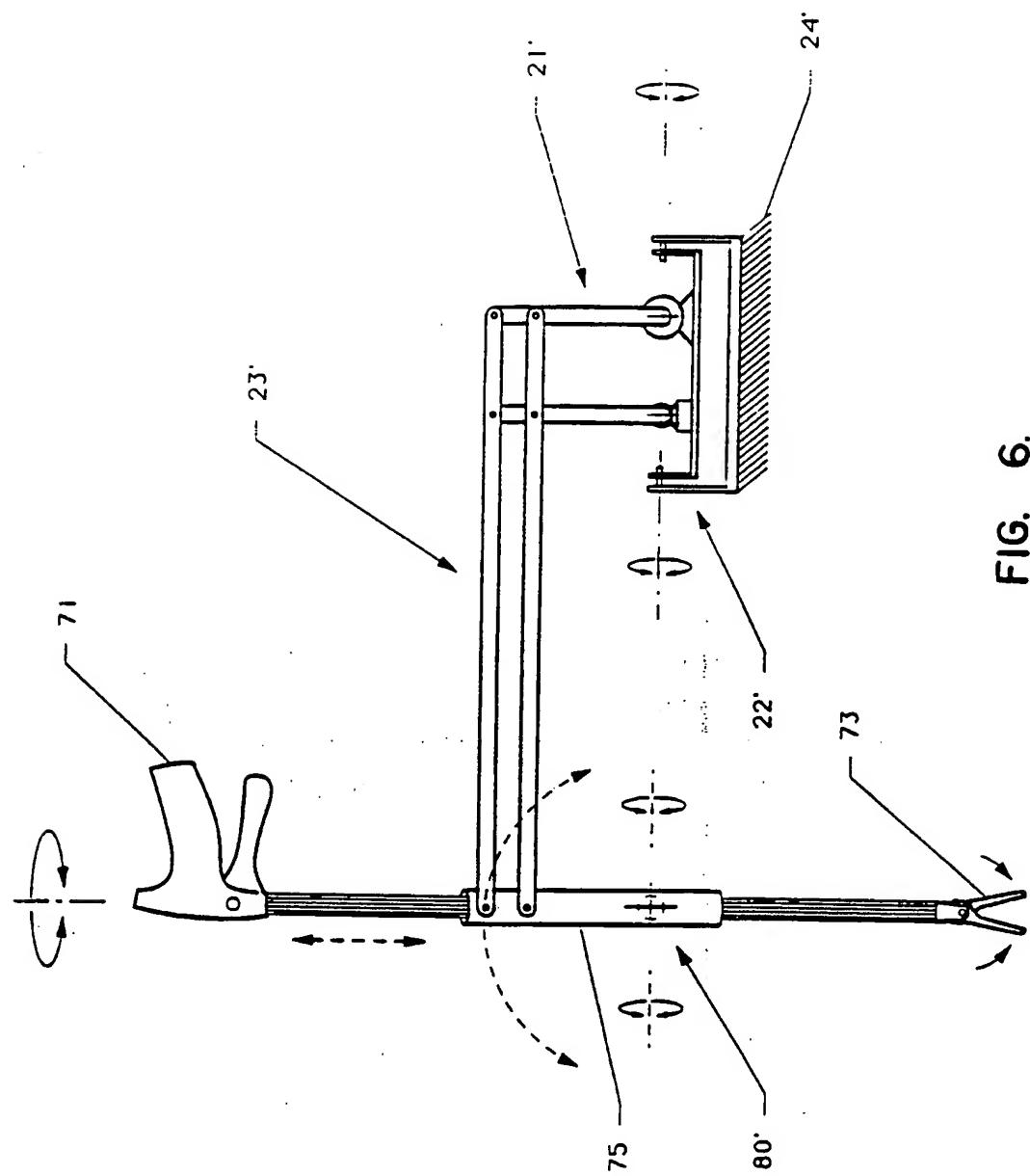
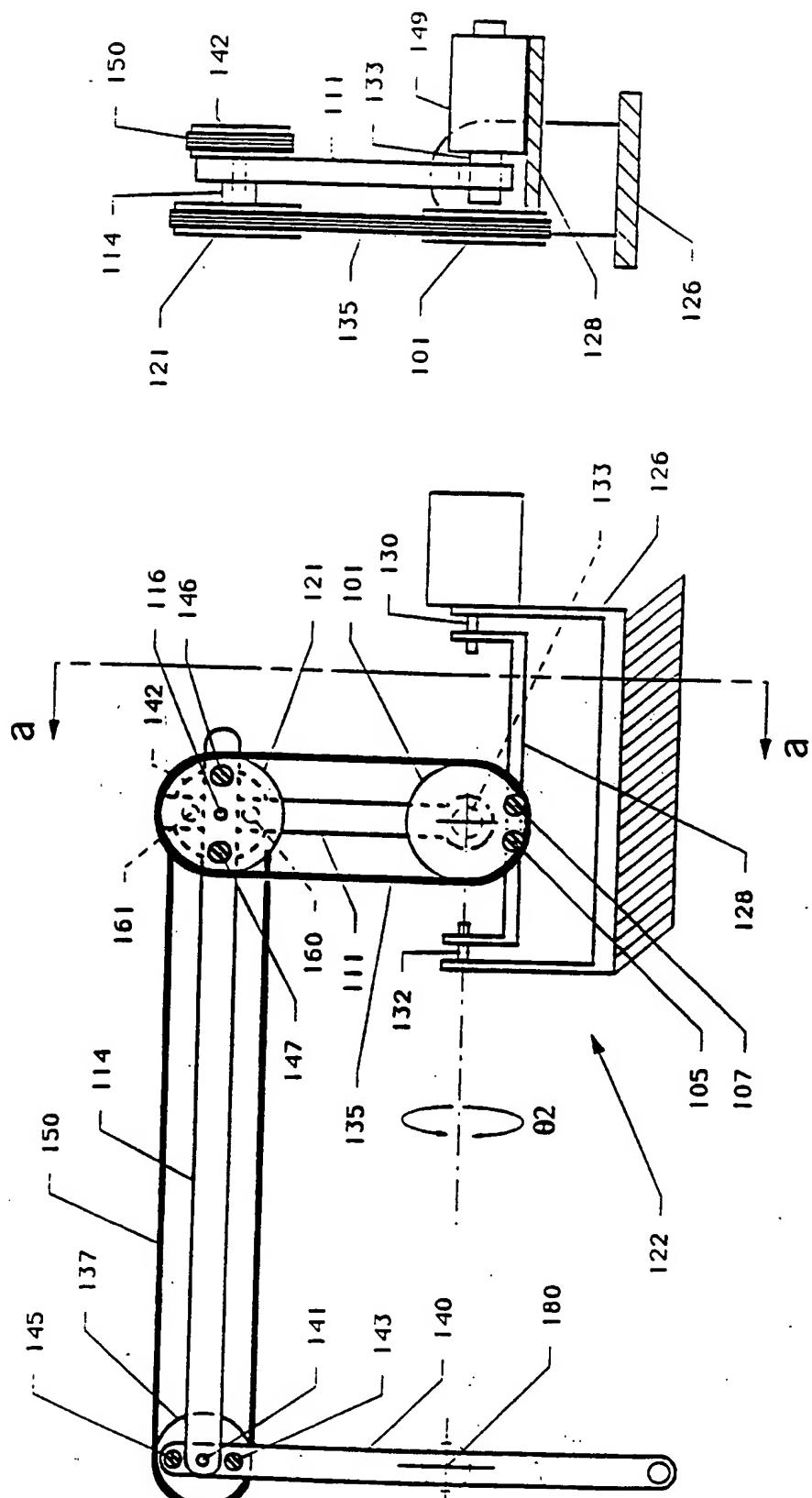


FIG. 6.

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FIGURE 7a

FIGURE 7

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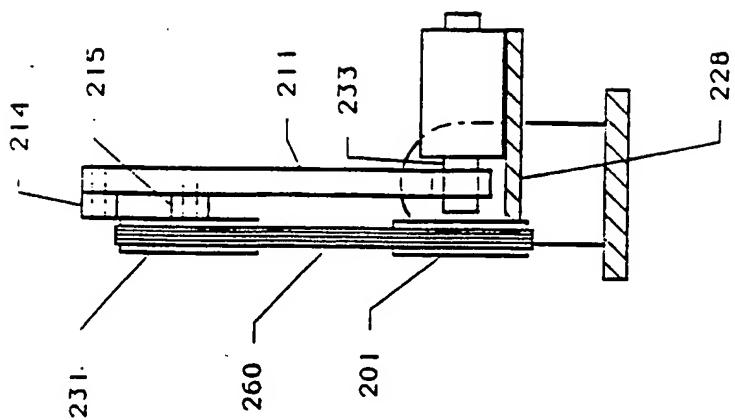
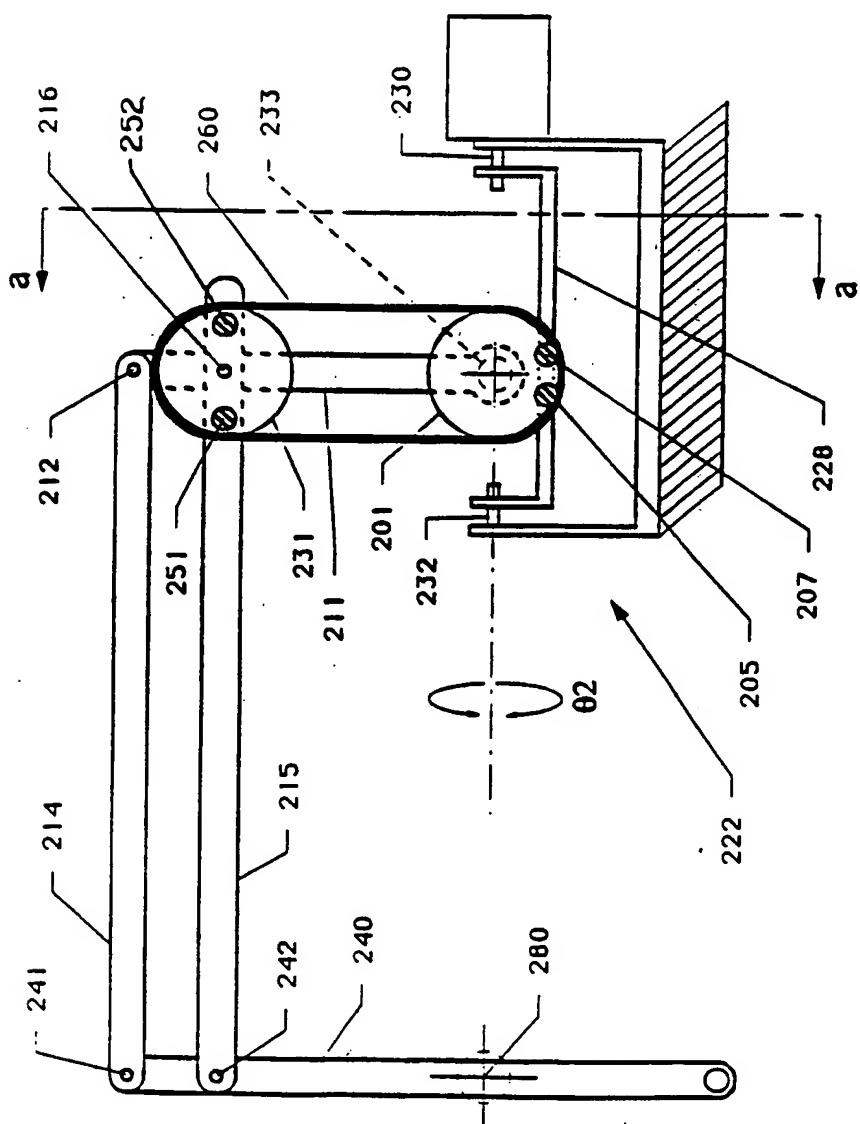


FIGURE 8a



## FIGURE 8

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## INTERNATIONAL SEARCH REPORT

International application No.

PCT/US94/04867

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :A61B 6/00

US CL :606/1

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 74/96, 479B, 479BF, 479BP; 414/917; 606/1, 130; 901/16, 21

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
NONEElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
NONE

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 5, 078,140, (KWOH), 07 January 1992. See entire document.	1-40
A, P	US, A, 5,219,351, (TEUBNER ET AL.), 15 June 1993. See entire document.	1-40
A, P	US, A, 5,257,998, (OTA ET AL.), 02 November 1993. See entire document.	1-40
A	US, A, 4,260,319, (MOTODA ET AL.), 07 April 1981. See entire document.	1-40
A	US, A, 5,060,532, (BARKER), 29 October 1991. See entire document.	1-40

 Further documents are listed in the continuation of Box C.  See patent family annex.

• Special categories of cited documents:	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"		document defining the general state of the art which is not considered to be of particular relevance
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"O"		document referring to an oral disclosure, use, exhibition or other means
"P"	"Z"	document published prior to the international filing date but later than the priority date claimed

Date of the actual completion of the international search 01 AUGUST 1994	Date of mailing of the international search report 30 AUG 1994
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